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# MOVING PARTICLE SIMULATION FOR FREE SURFACE AND MULTI-PHASE FLOWS

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**Key words:** MPS, Tsunami, Multi-Phase Flow, Phase Change.

**Abstract.** This document provides particle simulation for free surface and multi-phase flows using the MPS (Moving Particle Simulation) method.

## 1 INTRODUCTION

Particle simulation is fitted to complex motion of free surfaces and multi-phase interfaces. The MPS (Moving Particle Simulation) method [1] has been used and is being developed for free surface and multi-phase flows. A review paper was published in [2]. Tsunami invasion with floating objects is one of the important issues which were recognized in the large tsunami disaster in Japan on March 11, 2011. Severe accident analysis which accompanies complex phase change processes in nuclear reactors is another challenging subject.

## 2 FREE SURFACE FLOWS

### 2.1 Tsunami

Large-scale simulation is necessary for three-dimensional analysis of tsunami invasion. Figure 1 shows an example [3]. 6,300,300 particles were used for 1,000x600m area. The particle size was 1m. The inflow boundary condition with an inflow velocity of 10m/s was set at offshore. Real geometries, which are supplied by private companies and a government organization, can be converted to the input data of the particle simulation.

Explicit MPS methods [4, 5] have been proposed without solving the Poisson equation of pressure. The time step width $\Delta t$ in the explicit MPS method can be the same as that in the semi-implicit MPS method when the Mach number is 0.2 [5]. Thus, the calculation speed is much faster in the explicit MPS method. The calculation time of the explicit method obeys $O(N^{1.0})$, where $N$ represents the number of particles. In the semi-implicit method, the calculation time is $O(N^{1.5})$. Therefore, the explicit algorithm is to be much faster in a larger problem.

There were a lot of damages due to floating objects, such as ships moored in a port, on March 11. The particle simulation can easily be applied to such problems involving the interaction between fluid flow and floating rigid bodies [6].

### 2.2 Lifeboat

Free fall of a lifeboat was analyzed in three dimensions [7]. The acceleration should be kept low for the human safety when it drops onto the sea surface. The lifeboat was represented by particles os which the relative coordinates were fixed as a rigid body. The interaction between the fluid flow and the rigid body was considered. Figure 2 shows a calculation result with a skid angle of 30 degrees. Splashing from the sea surface is observed. The calculated acceleration agreed well with the experimental one.

**Figure 1**: Tsunami invasion to the coast

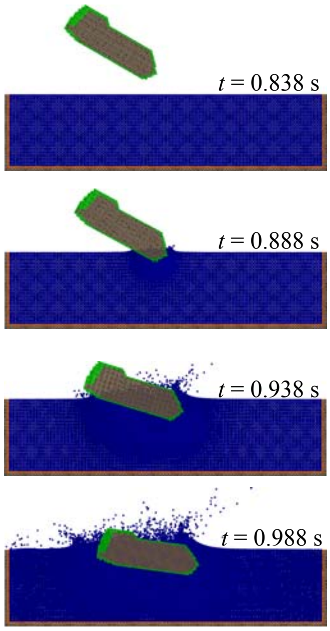



**Figure 2**: Dropping of a lifeboat onto the sea surface with a skid angle of 30 degrees

## 3 MULTI-PHASE FLOWS

### 3.1 Basic Processes

Basic processes of two-phase flows have been solved by the MPS method: oscillation of a square droplet due to surface tension, single droplet breakup, jet breakup and single bubble rising [2]. These results were compared with analytical solution or experimental observation.

Bubble growth and departure from a heated wall in nucleate boiling of water was calculated at atmospheric pressure using the MAS-MAFL (Meshless Advection using Flow-directional Local-grid) method which enables us ALE (Arbitrary Lagrangian-Eulerian) approach in the meshless framework [8]. In nucleate boiling of water, we need to analyze thin boundary layers developing on the heated wall and the bubble surface. Small particles were located in the boundary layers and they were moved arbitrary to keep them inside the layers. Figure 3 shows the calculation result. We can see that the bubble expands due to the heat from the bottom wall and that the growth is terminated by the heat balance between boiling and condensation. The bubble radius is provided in Fig.4. The growth stops at around 7ms which agrees well with experimental results. The calculated heat transfer is also in good agreement with that of the experiment.

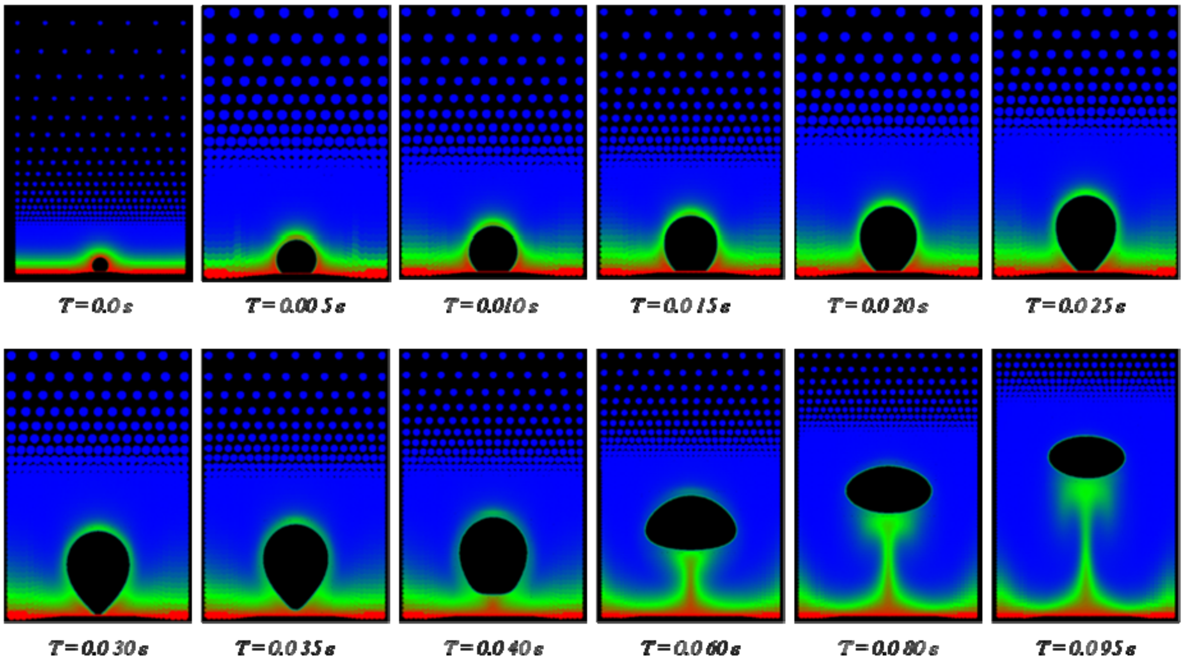



**Figure 3**: Subcooled boiling of water; pressure 1atm, wall temperature 110°C, bulk temperature 96°C, initial bubble diameter 0.3mm, contact angle 45°

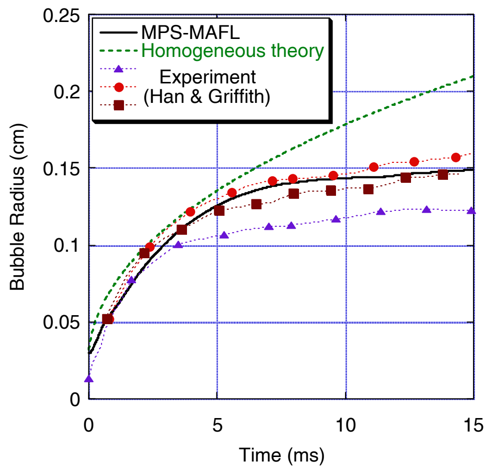



**Figure 4**: Bubble radius

## 3.2 Applications

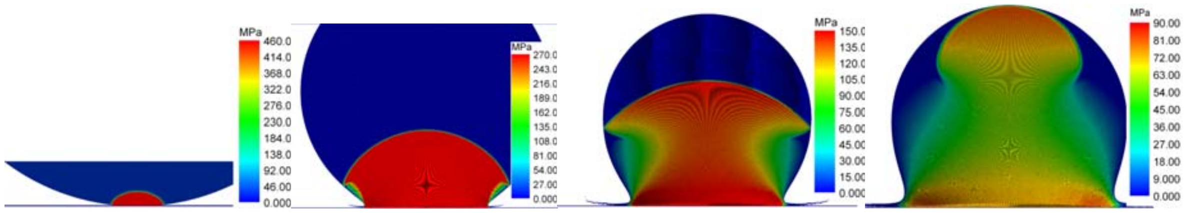
Liquid droplet impingement (LDI) is one of the principal mechanisms of the pipe wall thinning in nuclear power plants. Pressure wave propagation in a droplet was analyzed with an impinging velocity of 200m/s and a droplet diameter of 50μm (Fig.5) [9, 10]. A compressible-incompressible unified algorithm was employed. We can find that high pressure appears when the droplet impinges on the wall surface and it propagates upward in the droplet. The calculated pressure agreed with those of the existing correlations.

When high temperature molten core is dropped into low temperature coolant, a vapor explosion may occur. The cause of the vapor explosions is rapid fragmentation of the molten material and subsequent increase of the heat transfer area between high and low temperature liquids. The MPS method was used to analyze single droplet fragmentation (Fig.6) [11, 12]. Multiple water jets impinged onto a molten tin droplet, which caused sharp spikes on the droplet surface. This behavior agreed well with X-ray photographs taken in the fragmentation process.

The MPS method has been applied to various phenomena in severe accidents of nuclear reactors: molten core-concrete interaction (MCCI), in-vessel retention (IVR), molten core spreading etc [2].

## 4 CONCLUSIONS

Particle simulation has been used for complex free surface flows, such as tsunami invasion to the coast and ship-water interaction. Basic processes of multi-phase flows are analyzed, such as droplet oscillation due to surface tension, droplet breakup, jet breakup, a rising bubble and nucleate boiling. Complex behaviors in severe accidents of nuclear reactors have been analyzed by the MPS method.




$6.9 \times 10^{-10}$ s    $9.78 \times 10^{-9}$ s    $1.97 \times 10^{-8}$ s    $2.97 \times 10^{-8}$ s

**Figure 5**: Liquid droplet impingement onto a dry wall; droplet diameter $5 \times 10^{-5}$m, velocity 200m/s

0.0ms    0.1ms    0.2ms    0.3ms    0.4ms

**Figure 6**: Fragmentation of a molten tin droplet

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